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by

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# LIQUID CARRY OVER IN A HORIZONTAL TUBE EVAPORATOR

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## ABSTRACT

Carry over of liquid droplets was studied in a semi-commercial horizontal-tube evaporator for 10 and 20 per cent sodium chloride, 20 and 24 per cent sodium sulfate and 23 per cent magnesium sulfate solutions. Carry over was caused by entrainment of small liquid droplets by the rising vapor, splashing of liquid from the evaporator directly into the condenser, and foaming of the solution into the overhead condenser.

Entrainment losses were low, the maximum loss was about 180 lb. of liquor/million lb. of vapor. Entrainment in pounds per million pounds decreased with increased heat flux density and increased boiling point. A relationship between entrainment and the over-all heat transfer coefficient was attributed to the fact that both were functions of the size and number of the vapor bubbles formed.

Splashing occurred at the high heat flux densities, and a higher heat flux density was required to cause splashing at the higher boiling points than at the lower. This study showed that splashing did not occur if one cubic foot of vapor space was provided for every cubic foot per second of vapor evaporated. Since splashing losses are large, attention should be given to splashing in the design of evaporators.

Foaming occurred with the sodium chloride solutions in concentrations below 10 per cent and over 25 per cent, with the sodium sulfate solutions below 20 per cent and with the magnesium sulfate solutions below 10 per cent. There was a greater tendency for foaming at the higher boiling points.

## INTRODUCTION

The carry over of liquid particles is of immediate concern in the design and operation of evaporators. Large carry over results in loss of a valuable product while even small carry-over losses are important when the overhead is to be used as boiler feed water. Some work has been done on evaluating the factors affecting carry over in basket and forced-circulation-type evaporators and steam boilers. However, no comprehensive study of carry over in a horizontal-tube evaporator has been reported in the literature.

Carry over in a horizontal-tube evaporator can be caused by:

1. Entrainment of small liquid droplets by the rising vapor. Liquid droplets are thrown upward into the vapor space by the action of the escaping vapor and are carried overhead into the condenser by the rising vapor.

2. Splashing of liquid from the evaporator directly into the condenser. When the solution is boiled violently, escaping vapor forces the liquid in the center upward—like in a fountain. If the boiling is violent enough, the top of the fountain reaches to the top of the evaporator and liquid is splashed into the overhead condenser.

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3. Foaming of the solution into the overhead condenser. Foam forms when the force inside the vapor bubbles is not sufficient to burst the liquid film that surrounds the vapor bubble. Thus, a layer of vapor bubbles surrounded by a liquid film is formed on the evaporating surface. This layer builds and rises until it passes overhead into the condenser.

This investigation studied the factors affecting carry-over losses from entrainment, splashing and foaming in a horizontal-tube evaporator. Attention was given to splashing because it was felt that this is an important consideration in the design of evaporators.

#### PREVIOUS INVESTIGATIONS

Information in the literature on carry over in evaporators is very meager. Norris,<sup>19</sup> in 1910, indicated that carry over occurred in sugar evaporators (horizontal tubes) and mentioned that more carry over occurred in the last effect. Kerr,<sup>16</sup> in 1913, claimed that carry over increased with heat flux density but that neither the vacuum in the vapor space nor the velocity of the vapor affected the carry over to any measured extent.

Cessna and Badger<sup>3</sup> found that in a forced-circulation evaporator, carry over was proportional to the mass velocity of the vapor. However, in this type of evaporator, the vapor-liquid mixture leaves the tubes at a high velocity and impinges against an umbrella-type deflector. The liquid fans out to form a curtain of liquid through which the rising vapor must pass.

Badger<sup>2</sup> mentioned that 20 to 40 lb./hr. of evaporation per square foot of evaporating surface is the maximum allowable to prevent excessive carry over, but he did not state the effect of different types of evaporators and various operating conditions.

A rather complete theoretical discussion has been given by Hausbrand<sup>13</sup> on the effect of a current of vapor on liquid droplets suspended in this vapor. Hausbrand derived from theoretical considerations, equations for the height to which liquid droplets will rise when a current of vapor acts on them. Hausbrand hypothesized that under certain conditions hollow drops, which are bubbles of steam surrounded by a film of liquid, will be carried overhead. He claimed also that these hollow drops, together with very small drops of liquid, constitute the major source of loss in evaporation.

Considerable work has been done on carry over in steam boilers by Foulk,<sup>4-11</sup> Behrman,<sup>1</sup> Hall,<sup>12</sup> Hancock,<sup>14</sup> Mumford,<sup>17</sup> Niehaus,<sup>18</sup> Strubin,<sup>20</sup> and Vorkauf.<sup>21</sup> The most informative of these was the work of Foulk who explained the large carry over in steam boilers was due to (1) foaming, (2) violent boiling that throws slugs of water against the steam outlet, and (3) lifting of boiler water by the sudden formation of steam bubbles throughout the mass.

Foulk also listed several generalizations on the formation and behavior of foams as follows:

1. Pure liquids do not foam.
2. Some substance must be dispersed molecularly or colloiddally in a liquid to make it foam. The nature of the added substance has little effect since nearly all substances induce foaming. However, a few thousandths of one per cent of some substances produce more foam than several per

cents of others. Also, there are great differences in the stability of different foams.

3. Qualitatively speaking, it does not matter whether the added substance is positively or negatively absorbed. Since positively absorbed ions or molecules lower the surface tension and negatively absorbed ions raise the surface tension, it is seen that there is no correlation between foam and surface tension.

4. Certain substances have the power of destroying foam and of preventing the formation of foam. Some, at least, of these anti-foams may destroy or inhibit the foams produced by positively absorbed or negatively absorbed substances. Castor oil, for example, destroys the foam produced by the positively absorbed saponin and that produced by negatively absorbed sodium sulfate. The anti-foam is effective, at times, in concentrations of only a few thousandths of one per cent.

5. The presence of solid matter will, at times, help to stabilize the foam. Certain solids that are not wetted will settle and have no effect on film stabilization.

The work on steam boilers just referred to is not directly applicable to the study of carry over in a horizontal-tube evaporator. However, in spite of this, this work supplied definite leads as to the factors affecting carry over in evaporators, as shown herewith.

#### APPARATUS AND OPERATING PROCEDURE

A schematic diagram of the semi-commercial criss-cross horizontal-tube evaporator and its accessories is shown in Figure 1. The evaporator has a vapor space 5 ft. high and 3 ft. I.D. and a liquid body 4 ft. high and 2½ ft. I.D. The unit has capacity to evaporate about a ton of water per hour.

The heating surface located in the liquid body consisted of two tube bundles perpendicular to each other, each bundle containing seventy-two horizontal admiralty metal tubes, ⅞ in. O.D., 16 gauge and 26.5 in. in effectual length. Steam was used as the heating medium. The overhead vapor was condensed in a water-cooled vertical heat exchanger with the water coolant on the shell side.

For a series of runs, the desired solution was made up in the feed tank (*A*) and pumped to the evaporator. Steam was supplied to the heating surface at the desired pressure, which was recorded in manometer (*K*). The pressure in the vapor space was maintained by a steam-driven wet vacuum pump and was controlled by a solenoid vacuum break which operated automatically with the vacuum manometer. Steam condensate and overhead condensate were collected and measured in calibrated cylindrical tanks.

The liquid level in the evaporator (as measured by a sight glass) was maintained constant by making up the evaporated water with water from tank (*B*). The water was supplied to the evaporator at a temperature about 5° F. less than in the evaporator.

Each run was of forty minutes duration and was conducted after equilibrium condition had been established. For each run, the following measurements were made:

1. The amount of steam used was determined from the amount of steam condensate collected in calibrated tanks.



2. The amount of water evaporated was determined from the amount of overhead condensate collected in calibrated tanks.

3. Temperatures (a reading every four minutes) of the overhead vapor, overhead condensate, steam condensate and make up water were obtained from calibrated thermometers located as shown in Figure 1.

4. Pressures (reading every four minutes) on the vapor space and in the steam chest were measured by mercury manometers.

5. The concentration of the solution in the liquid body was determined from analyses of samples taken at the beginning and end of the run.

6. The amount of carry over was measured by determining the concentration of salt in the overhead condensate. The concentration of the salt

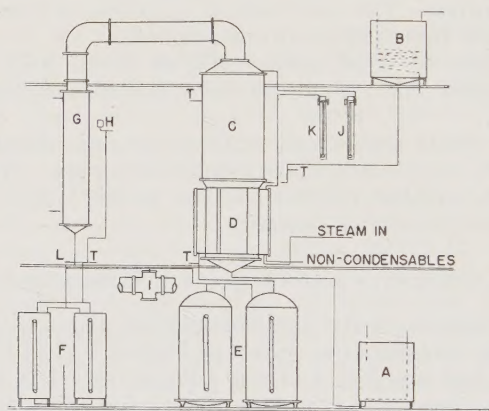


FIG. 1. Flow Diagram of Apparatus.

- |                     |                         |
|---------------------|-------------------------|
| A—Feed tank         | G—Condenser             |
| B—Make Up tank      | H—Solenoid vacuum break |
| C—Vapor space       | I—Vacuum main           |
| D—Heating surface   | J—Vapor space manometer |
| E—Steam drips tanks | K—Steam chest manometer |
| F—Over heads tanks  | L—Conductivity cell     |

T—Temperature

was determined from the conductivity of the solution. A Leeds and Northrup (No. 4931) conductivity cell was used. The cell was inserted directly into the overhead condensate line by a suitable pipe fitting and packing gland arrangement. The resistance was recorded on a standard Leeds and Northrup (No. 4960) portable electrolytic conductivity cell bridge. Readings were taken on the conductivity cell bridge and the amount of salt in the solution determined from a previously determined calibration chart.

### ENTRAINMENT

Approximately 130 runs were made to study carry-over losses from entrainment. A summary of the results of these runs is given in Table 1.

TABLE 1.—SUMMARY OF ENTRAINMENT RUNS

| Run No. | Boiling Point of Solution °F. | Sat. Steam Temp. °F. | $\Delta T$ °F. | 10 Per Cent NaCl Solution | Heat Flux Density B.t.u./ (hr.) (sq.ft.) | Over-all Heat Transfer Coefficient B.t.u./ (hr.) (sq.ft.) (° F.) | Mass Velocity lb./ (hr.) (sq.ft.) | Lb. Liquor Entrained per 10 <sup>6</sup> lb. vapor | Lb. Liquor Entrained per hour $\times 10^4$ |
|---------|-------------------------------|----------------------|----------------|---------------------------|------------------------------------------|------------------------------------------------------------------|-----------------------------------|----------------------------------------------------|---------------------------------------------|
| M-1     |                               |                      |                |                           |                                          |                                                                  |                                   |                                                    |                                             |
| 1       | 134.8                         | 160.5                | 25.7           | 5,020                     | 195                                      | 48.4                                                             | 42.9                              | 147                                                |                                             |
| 2       | 134.8                         | 170.6                | 35.8           | 10,690                    | 298                                      | 105.9                                                            | 22.9                              | 171                                                |                                             |
| 4       | 140.4                         | 154.9                | 14.5           | 1,810                     | 125                                      | 12.7                                                             | 107.3                             | 97                                                 |                                             |
| 5       | 140.4                         | 168.1                | 27.7           | 5,565                     | 201                                      | 49.7                                                             | 35.3                              | 124                                                |                                             |
| 7       | 139.8                         | 155.0                | 15.2           | 1,989                     | 131                                      | 16.6                                                             | 60.1                              | 71                                                 |                                             |
| N-1     |                               |                      |                |                           |                                          |                                                                  |                                   |                                                    |                                             |
| 1       | 166.3                         | 176.7                | 10.4           | 1,417                     | 136                                      | 7.6                                                              | 181.5                             | 98                                                 |                                             |
| 2       | 162.6                         | 182.9                | 20.3           | 4,520                     | 223                                      | 38.8                                                             | 67.3                              | 184                                                |                                             |
| 3       | 160.0                         | 189.0                | 29.0           | 8,030                     | 276                                      | 78.4                                                             | 33.9                              | 188                                                |                                             |
| 4       | 161.7                         | 195.0                | 33.3           | 10,120                    | 304                                      | 98.9                                                             | 54.2                              | 380                                                |                                             |
| 8       | 161.5                         | 195.7                | 34.2           | 11,100                    | 324                                      | 108.2                                                            | 31.7                              | 242                                                |                                             |
| O-1     |                               |                      |                |                           |                                          |                                                                  |                                   |                                                    |                                             |
| 1       | 188.3                         | 212.0                | 23.7           | 7,810                     | 330                                      | 76.0                                                             | 59.9                              | 322                                                |                                             |
| 2       | 188.3                         | 202.1                | 13.8           | 3,700                     | 268                                      | 32.8                                                             | 63.1                              | 146                                                |                                             |
| 3       | 188.3                         | 207.1                | 18.8           | 4,650                     | 248                                      | 45.6                                                             | 58.6                              | 189                                                |                                             |
| 4       | 188.3                         | 217.7                | 29.4           | 7,910                     | 269                                      | 77.4                                                             | 52.6                              | 288                                                |                                             |
| 5       | 188.3                         | 230.6                | 42.3           | 15,020                    | 356                                      | 152.8                                                            | 32.8                              | 352                                                |                                             |
| 6       | 188.5                         | 206.2                | 17.7           | 4,100                     | 232                                      | 38.1                                                             | 68.4                              | 184                                                |                                             |
| 7       | 188.5                         | 219.1                | 30.6           | 11,490                    | 375                                      | 114.0                                                            | 43.4                              | 349                                                |                                             |
| P-1     |                               |                      |                |                           |                                          |                                                                  |                                   |                                                    |                                             |
| 1       | 213.1                         | 226.7                | 13.6           | 3,380                     | 249                                      | 33.8                                                             | 63.7                              | 152                                                |                                             |
| 2       | 213.1                         | 239.7                | 26.2           | 10,620                    | 405                                      | 105.7                                                            | 63.5                              | 473                                                |                                             |
| 3       | 213.1                         | 245.0                | 31.9           | 13,700                    | 429                                      | 145.8                                                            | 52.2                              | 537                                                |                                             |
| 4       | 213.1                         | 250.5                | 37.4           | 15,750                    | 420                                      | 161.0                                                            | 44.8                              | 509                                                |                                             |
| 5       | 222.2                         | 222.2                | 9.1            | 2,200                     | 242                                      | 19.5                                                             | 63.4                              | 87                                                 |                                             |
| 6       | 213.7                         | 232.4                | 18.7           | 4,500                     | 241                                      | 41.2                                                             | 82.5                              | 240                                                |                                             |
| 7       | 213.7                         | 235.9                | 22.2           | 7,010                     | 315                                      | 70.1                                                             | 72.6                              | 360                                                |                                             |
| 8       | 213.7                         | 226.5                | 13.8           | 2,145                     | 155                                      | 18.9                                                             | 78.0                              | 141                                                |                                             |

TABLE 1.—(Continued)

| Run No.                   | Boiling Point of Solution °F. | Sat. Steam Temp. °F. | $\Delta T$ °F. | Heat Flux Density B.t.u./ (hr.) (sq.ft.) | Over-all Heat Transfer Coefficient B.t.u./ (hr.) (°F.) | Mass Velocity lb./ (hr.) (sq.ft.) | Lb. Liquor Entrained per 10 <sup>3</sup> lb. vapor | Lb. Liquor Entrained per hour $\times 10^3$ |
|---------------------------|-------------------------------|----------------------|----------------|------------------------------------------|--------------------------------------------------------|-----------------------------------|----------------------------------------------------|---------------------------------------------|
| 20 Per Cent NaCl Solution |                               |                      |                |                                          |                                                        |                                   |                                                    |                                             |
| R-1                       | 140.5                         | 168.7                | 28.2           | 5,150                                    | 183                                                    | 49.9                              | 15.4                                               | 54                                          |
| 2                         | 140.5                         | 179.0                | 38.5           | 9,900                                    | 257                                                    | 97.7                              | 11.0                                               | 76                                          |
| 4                         | 140.5                         | 161.6                | 21.1           | 2,490                                    | 118                                                    | 22.4                              | 56.5                                               | 89                                          |
| 5                         | 142.3                         | 177.1                | 34.8           | 8,210                                    | 236                                                    | 83.5                              | 12.8                                               | 75                                          |
| 6                         | 139.8                         | 159.5                | 19.7           | 2,695                                    | 137                                                    | 24.1                              | 24.2                                               | 41                                          |
|                           |                               |                      |                |                                          |                                                        |                                   |                                                    |                                             |
| S-1                       | 191.6                         | 210.7                | 19.1           | 5,200                                    | 272                                                    | 50.2                              | 47.6                                               | 169                                         |
| 2                         | 190.6                         | 213.0                | 22.4           | 4,110                                    | 183                                                    | 39.1                              | 49.1                                               | 135                                         |
| 3                         | 191.2                         | 222.9                | 31.7           | 8,450                                    | 266                                                    | 84.2                              | 33.6                                               | 200                                         |
| 4                         | 191.6                         | 230.0                | 38.4           | 13,000                                   | 338                                                    | 129.1                             | 27.2                                               | 248                                         |
| 5                         | 190.6                         | 204.3                | 13.7           | 3,710                                    | 271                                                    | 36.2                              | 42.7                                               | 109                                         |
| 6                         | 190.2                         | 224.5                | 34.3           | 11,100                                   | 324                                                    | 110.9                             | 30.6                                               | 239                                         |
| 7                         | 190.2                         | 217.0                | 26.8           | 7,100                                    | 265                                                    | 70.7                              | 41.1                                               | 205                                         |
| 8                         | 190.2                         | 203.8                | 13.6           | 2,105                                    | 155                                                    | 19.8                              | 50.7                                               | 71                                          |
|                           |                               |                      |                |                                          |                                                        |                                   |                                                    |                                             |
| T-1                       | 219.0                         | 236.3                | 17.3           | 4,000                                    | 231                                                    | 38.0                              | 60.2                                               | 162                                         |
| 2                         | 219.0                         | 242.0                | 23.0           | 7,150                                    | 311                                                    | 70.0                              | 55.5                                               | 275                                         |
| 3                         | 219.0                         | 250.0                | 31.0           | 11,000                                   | 355                                                    | 111.8                             | 42.0                                               | 332                                         |
| 4                         | 219.0                         | 257.2                | 38.2           | 14,180                                   | 371                                                    | 143.5                             | 34.2                                               | 347                                         |
| 5                         | 219.1                         | 260.0                | 40.9           | 16,020                                   | 391                                                    | 163.0                             | 32.5                                               | 374                                         |
| 6                         | 219.1                         | 232.8                | 13.7           | 2,105                                    | 154                                                    | 18.0                              | 60.9                                               | 76                                          |
| 7                         | 219.1                         | 230.3                | 11.2           | 1,115                                    | 99                                                     | 9.0                               | 44.2                                               | 28                                          |
|                           |                               |                      |                |                                          |                                                        |                                   |                                                    |                                             |
| U-1                       | 167.1                         | 185.7                | 18.6           | 3,160                                    | 170                                                    | 28.7                              | 33.2                                               | 67                                          |
| 2                         | 167.1                         | 193.8                | 26.7           | 6,210                                    | 232                                                    | 60.2                              | 25.8                                               | 110                                         |
| 3                         | 167.1                         | 201.7                | 34.6           | 9,310                                    | 269                                                    | 91.1                              | 19.9                                               | 128                                         |
| 4                         | 167.0                         | 204.3                | 37.3           | 11,190                                   | 300                                                    | 111.0                             | 17.4                                               | 137                                         |



TABLE 1.—(Continued)

| Run No.                                              | Boiling Point of Solution °F. | Sat. Steam Temp. °F. | $\Delta T$ °F. | Heat Flux Density B.t.u./ (hr.) (sq.ft.) | Over-all Heat Transfer Coefficient B.t.u./ (hr.) (°F.) (sq.ft.) | Mass Velocity lb./ (hr.) (sq.ft.) | Lb. Liquor Entrained per 10 <sup>6</sup> lb. vapor | Lb. Liquor Entrained per hour $\times 10^3$ |
|------------------------------------------------------|-------------------------------|----------------------|----------------|------------------------------------------|-----------------------------------------------------------------|-----------------------------------|----------------------------------------------------|---------------------------------------------|
| 20 Per Cent Na <sub>2</sub> SO <sub>4</sub> Solution |                               |                      |                |                                          |                                                                 |                                   |                                                    |                                             |
| AA-1                                                 | 141.4                         | 153.5                | 12.1           | 2,958                                    | 170                                                             | 18.9                              | 87.0                                               | 114                                         |
| 2                                                    | 141.4                         | 173.5                | 32.1           | 8,860                                    | 276                                                             | 86.6                              | 34.3                                               | 211                                         |
| 3                                                    | 139.1                         | 163.1                | 24.0           | 5,420                                    | 226                                                             | 50.4                              | 57.4                                               | 204                                         |
| 4                                                    | 139.1                         | 170.8                | 31.7           | 8,050                                    | 254                                                             | 77.9                              | 32.4                                               | 178                                         |
| 5                                                    | 139.1                         | 158.3                | 19.2           | 3,310                                    | 173                                                             | 30.6                              | 82.0                                               | 178                                         |
| 6                                                    | 140.1                         | 153.4                | 13.3           | 1,295                                    | 97                                                              | 10.2                              | 51.5                                               | 37                                          |
| 7                                                    | 140.1                         | 163.1                | 23.0           | 4,560                                    | 197                                                             | 42.5                              | 62.3                                               | 225                                         |
| 8                                                    | 140.1                         | 173.5                | 33.4           | 8,350                                    | 250                                                             | 80.3                              | 35.1                                               | 199                                         |
| 9                                                    | 140.1                         | 165.0                | 24.9           | 5,570                                    | 224                                                             | 53.6                              | 54.6                                               | 207                                         |
| 24 Per Cent Na <sub>2</sub> SO <sub>4</sub> Solution |                               |                      |                |                                          |                                                                 |                                   |                                                    |                                             |
| AB-1                                                 | 164.6                         | 175.4                | 10.8           | 1,230                                    | 114                                                             | 97.8                              | 49.0                                               | 34                                          |
| 2                                                    | 164.6                         | 179.6                | 15.0           | 3,270                                    | 218                                                             | 28.6                              | 69.2                                               | 140                                         |
| 3                                                    | 164.6                         | 186.2                | 21.6           | 5,290                                    | 244                                                             | 50.2                              | 82.2                                               | 292                                         |
| 4                                                    | 164.6                         | 192.3                | 27.7           | 7,290                                    | 263                                                             | 71.4                              | 67.9                                               | 343                                         |
| 5                                                    | 164.2                         | 176.8                | 12.6           | 1,697                                    | 135                                                             | 127.8                             | 90.0                                               | 81                                          |
| 6                                                    | 164.2                         | 185.5                | 21.3           | 4,550                                    | 214                                                             | 42.5                              | 88.7                                               | 267                                         |
| 7                                                    | 164.0                         | 194.4                | 30.4           | 9,430                                    | 310                                                             | 84.8                              | 53.4                                               | 321                                         |
| 11                                                   | 164.5                         | 178.8                | 14.3           | 2,800                                    | 196                                                             | 24.8                              | 74.0                                               | 130                                         |
| 24 Per Cent Na <sub>2</sub> SO <sub>4</sub> Solution |                               |                      |                |                                          |                                                                 |                                   |                                                    |                                             |
| BA-1                                                 | 139.2                         | 173.6                | 34.4           | 7,940                                    | 231                                                             | 77.2                              | 53.1                                               | 289                                         |
| 2                                                    | 139.2                         | 166.5                | 27.3           | 5,700                                    | 208                                                             | 55.3                              | 51.0                                               | 199                                         |
| 3                                                    | 139.8                         | 157.9                | 18.1           | 2,710                                    | 150                                                             | 22.8                              | 82.5                                               | 133                                         |
| 4                                                    | 139.8                         | 163.0                | 23.2           | 5,090                                    | 219                                                             | 48.8                              | 55.4                                               | 190                                         |
| 5                                                    | 139.8                         | 169.1                | 29.3           | 6,950                                    | 237                                                             | 65.5                              | 43.6                                               | 202                                         |
| 6                                                    | 140.9                         | 154.0                | 13.1           | 1,440                                    | 110                                                             | 11.2                              | 59.6                                               | 47                                          |
| 7                                                    | 140.7                         | 176.5                | 35.8           | 9,090                                    | 254                                                             | 89.4                              | 25.3                                               | 160                                         |

TABLE 1.—(Continued)

| Run No. | Boiling Point of Solution ° F. | Sat. Steam Temp. ° F. | $\Delta T$ ° F. | 24 Per Cent $\text{Na}_2\text{SO}_4$ Solution | Heat Flux Density B.t.u./ (hr.) (sq.ft.) | Over-all Heat Transfer Coefficient B.t.u./ (hr.) (° F.) (sq.ft.) | Mass Velocity lb./ (hr.) (sq.ft.) | Lb. Liquor Entrained per 10 <sup>3</sup> lb. vapor | Lb. Liquor Entrained per hour $\times 10^4$ |
|---------|--------------------------------|-----------------------|-----------------|-----------------------------------------------|------------------------------------------|------------------------------------------------------------------|-----------------------------------|----------------------------------------------------|---------------------------------------------|
| BB-1    | 166.0                          | 181.6                 | 15.6            | 3,050                                         | 195                                      | 27.9                                                             | 90.2                              | 178                                                |                                             |
|         | 166.0                          | 176.4                 | 10.4            | 1,224                                         | 118                                      | 7.6                                                              | 68.3                              | 37                                                 |                                             |
|         | 166.0                          | 183.3                 | 17.3            | 3,560                                         | 206                                      | 33.2                                                             | 92.0                              | 193                                                |                                             |
|         | 166.4                          | 188.6                 | 22.2            | 5,280                                         | 238                                      | 53.0                                                             | 77.6                              | 291                                                |                                             |
|         | 166.4                          | 184.9                 | 18.5            | 3,600                                         | 195                                      | 34.4                                                             | 66.4                              | 161                                                |                                             |
|         | 166.4                          | 194.2                 | 27.8            | 7,950                                         | 286                                      | 77.8                                                             | 46.0                              | 253                                                |                                             |
| CC-1    | 166.0                          | 191.7                 | 25.7            | 7,080                                         | 275                                      | 69.9                                                             | 52.4                              | 259                                                |                                             |
|         | 166.0                          | 185.6                 | 19.6            | 4,000                                         | 204                                      | 36.4                                                             | 88.1                              | 226                                                |                                             |
| BC-1    | 191.3                          | 201.3                 | 10.0            | 2,490                                         | 249                                      | 20.5                                                             | 101.2                             | 147                                                |                                             |
|         | 191.3                          | 213.0                 | 21.7            | 8,660                                         | 399                                      | 83.7                                                             | 79.2                              | 469                                                |                                             |
|         | 191.6                          | 203.1                 | 11.5            | 1,952                                         | 170                                      | 15.4                                                             | 89.5                              | 106                                                |                                             |
|         | 191.6                          | 219.1                 | 27.5            | 8,920                                         | 324                                      | 88.1                                                             | 66.0                              | 412                                                |                                             |
|         | 191.6                          | 233.4                 | 41.8            | 16,630                                        | 398                                      | 170.8                                                            | 53.4                              | 643                                                |                                             |
|         | 191.6                          | 225.5                 | 33.9            | 13,960                                        | 411                                      | 141.5                                                            | 55.2                              | 552                                                |                                             |
|         | 191.3                          | 214.6                 | 23.3            | 6,870                                         | 295                                      | 75.0                                                             | 74.6                              | 395                                                |                                             |
|         | 191.2                          | 221.2                 | 30.0            | 12,500                                        | 416                                      | 114.5                                                            | 66.0                              | 535                                                |                                             |
|         | 191.8                          | 227.0                 | 35.2            | 11,290                                        | 320                                      | 113.0                                                            | 57.9                              | 463                                                |                                             |
|         | 190.0                          | 221.6                 | 31.6            | 12,920                                        | 410                                      | 128.4                                                            | 55.6                              | 504                                                |                                             |
|         | 190.0                          | 224.7                 | 34.7            | 15,500                                        | 446                                      | 164.0                                                            | 53.9                              | 622                                                |                                             |
|         | 190.0                          | 216.2                 | 26.2            | 7,740                                         | 295                                      | 76.6                                                             | 86.0                              | 466                                                |                                             |
| CC-4    | 214.1                          | 234.6                 | 19.5            | 6,750                                         | 346                                      | 67.4                                                             | 100.0                             | 476                                                |                                             |
|         | 214.1                          | 226.3                 | 12.2            | 3,480                                         | 285                                      | 32.5                                                             | 108.0                             | 248                                                |                                             |
|         | 214.1                          | 223.1                 | 9.0             | 1,291                                         | 144                                      | 9.2                                                              | 95.0                              | 62                                                 |                                             |
|         | 214.1                          | 239.3                 | 25.2            | 10,000                                        | 397                                      | 99.0                                                             | 86.5                              | 605                                                |                                             |
|         | 214.1                          | 244.0                 | 29.9            | 12,920                                        | 432                                      | 129.5                                                            | 74.9                              | 685                                                |                                             |
|         | 214.1                          | 247.6                 | 33.5            | 15,310                                        | 457                                      | 154.2                                                            | 66.2                              | 722                                                |                                             |

TABLE 1.—(Continued)

| Run No.                                | Boiling Point of Solution °F. | Sat. Steam Temp. °F. | $\Delta T$ °F. | Heat Flux Density B.t.u./ (hr.) (sq.ft.) | Over-all Heat Transfer Coefficient B.t.u./ (hr.) (sq.ft.) (°F.) | Mass Velocity lb./ (hr.) (sq.ft.) | Lb. Liquor Entrained per 10 <sup>3</sup> lb. vapor | Lb. Liquor Entrained per hour $\times 10^4$ |
|----------------------------------------|-------------------------------|----------------------|----------------|------------------------------------------|-----------------------------------------------------------------|-----------------------------------|----------------------------------------------------|---------------------------------------------|
| 23 Per Cent MgSO <sub>4</sub> Solution |                               |                      |                |                                          |                                                                 |                                   |                                                    |                                             |
| DD-1                                   | 212.0                         | 229.0                | 17.0           | 5,960                                    | 351                                                             | 58.5                              | 69.8                                               | 289                                         |
| 3                                      | 212.0                         | 242.2                | 30.2           | 13,890                                   | 458                                                             | 130.9                             | 43.8                                               | 405                                         |
| 4                                      | 212.0                         | 254.0                | 42.0           | 18,300                                   | 435                                                             | 182.0                             | 41.4                                               | 534                                         |
| 5                                      | 212.0                         | 244.4                | 32.4           | 13,760                                   | 425                                                             | 131.1                             | 42.6                                               | 395                                         |
| 6                                      | 212.0                         | 234.0                | 22.0           | 7,500                                    | 341                                                             | 73.5                              | 52.2                                               | 271                                         |
| 8                                      | 212.3                         | 240.9                | 28.6           | 9,330                                    | 326                                                             | 88.5                              | 37.3                                               | 234                                         |
| 11                                     | 212.3                         | 253.8                | 41.5           | 17,800                                   | 429                                                             | 181.0                             | 28.0                                               | 356                                         |
| EE-1                                   | 193.1                         | 220.9                | 27.8           | 7,940                                    | 285                                                             | 72.8                              | 65.8                                               | 339                                         |
| 2                                      | 188.3                         | 214.4                | 26.1           | 5,000                                    | 192                                                             | 46.2                              | 37.8                                               | 123                                         |
| 3                                      | 186.3                         | 226.6                | 40.3           | 11,950                                   | 296                                                             | 122.5                             | 21.3                                               | 184                                         |
| 4                                      | 186.2                         | 226.2                | 40.0           | 10,100                                   | 252                                                             | 101.0                             | 22.6                                               | 161                                         |
| 5                                      | 186.2                         | 232.7                | 46.5           | 15,520                                   | 334                                                             | 160.3                             | 17.8                                               | 201                                         |
| 6                                      | 185.1                         | 219.7                | 34.6           | 8,930                                    | 258                                                             | 90.2                              | 25.3                                               | 161                                         |
| 7                                      | 184.1                         | 212.0                | 27.9           | 3,960                                    | 142                                                             | 37.8                              | 33.9                                               | 90                                          |
| FF-1                                   | 144.0                         | 166.7                | 22.7           | 2,980                                    | 131                                                             | 28.0                              | 24.0                                               | 47                                          |
| 2                                      | 144.0                         | 175.5                | 31.5           | 5,780                                    | 183                                                             | 56.8                              | 21.0                                               | 84                                          |
| 3                                      | 144.0                         | 182.9                | 38.9           | 8,220                                    | 212                                                             | 81.6                              | 15.5                                               | 89                                          |
| 6                                      | 144.0                         | 184.3                | 40.3           | 8,700                                    | 216                                                             | 85.0                              | 17.3                                               | 103                                         |
| 7                                      | 143.1                         | 188.0                | 44.9           | 10,200                                   | 227                                                             | 97.3                              | 15.0                                               | 103                                         |
| 8                                      | 144.1                         | 174.5                | 30.4           | 5,250                                    | 173                                                             | 49.6                              | 22.6                                               | 79                                          |
| 9                                      | 141.9                         | 162.2                | 20.3           | 2,310                                    | 114                                                             | 21.5                              | 26.6                                               | 4                                           |
| GG-1                                   | 164.2                         | 189.6                | 25.4           | 4,050                                    | 160                                                             | 37.9                              | 28.4                                               | 76                                          |
| 2                                      | 164.6                         | 195.5                | 30.9           | 5,900                                    | 191                                                             | 55.2                              | 26.2                                               | 102                                         |
| 3                                      | 162.2                         | 204.0                | 41.9           | 11,950                                   | 285                                                             | 118.8                             | 13.6                                               | 113                                         |
| 5                                      | 158.9                         | 201.1                | 42.2           | 11,000                                   | 261                                                             | 109.0                             | 10.4                                               | 80                                          |



Experiments were conducted with 10 and 20 per cent sodium chloride solutions, 20 and 24 per cent sodium sulfate solutions, and a 23 per cent magnesium sulfate solution, for 140°, 164°, 188°, and 212° F. boiling points. In Table 1, entrainment is expressed both as pounds of liquor entrained per million pounds of vapor evaporated and as pounds of liquor entrained per hour.

Entrainment in pounds per million pounds of vapor is plotted against heat flux density for lines of constant boiling point in Figures 2 through 6 for the 10 per cent sodium chloride, 20 per cent sodium chloride, 20 per cent sodium sulfate, 24 per cent sodium sulfate, 23 per cent magnesium sulfate solutions, respectively. These figures show that entrainment in pounds per million pounds of vapor decreases with increased heat flux density and increases with increased boiling point. Entrainment is greatest for the 20 per cent sodium sulfate solution with the 24 per cent sodium sulfate, 10 per cent sodium chloride, 20 per cent sodium chloride, and 23 per cent magnesium sulfate solutions following in the order named. However, not in any case was the entrainment large. The highest value obtained was 181 lb./million lb. of vapor and this was obtained at a low heat flux density and a high boiling point.

As mentioned, entrainment can be expressed in pounds per hour. A typical plot of such data is given in Figure 7 where entrainment in pounds per hour is plotted against heat flux density for a 10 per cent sodium chloride solution. This figure shows that entrainment in pounds per hour increased with heat flux density. However, this statement and the one mentioned, that entrainment in pounds per million pounds of vapor decreases with heat flux density, are not incompatible. Entrainment in pounds per hour increased with heat flux density but at a slower rate than the increase in pounds of water evaporated with heat flux density. Thus, the over-all effect was a decrease in entrainment in pounds per million pounds of vapor with heat flux density. The effect of boiling point and type of solution on entrainment in pounds per hour was the same as for entrainment in pounds per million pounds of vapor.

Factors affecting entrainment in a horizontal-tube evaporator are many and it was beyond the scope of this study to evaluate them all. However, there is some evidence that the variables affecting the over-all heat transfer coefficient affect the amount of entrainment. This is suggested by the fair correlation obtained in Figure 8 where entrainment in pounds per hour is plotted against the over-all heat transfer coefficient.

The most important common variable affecting the heat transfer and the amount of entrainment is the number and size of the vapor bubbles formed on the tubes. Jacob and Fritz<sup>15</sup> have shown that the greater the number of vapor bubbles formed the greater the heat transfer coefficient. They demonstrated this by boiling water at approximately the same rate on two surfaces with one covered with oil to reduce the number of bubbles formed. The untreated surface, which gave off a large number of small bubbles, had a much higher heat transfer coefficient than the oil treated surface, which gave off a small number of large bubbles.

Since, as shown in Figure 8 (the data for Figure 8 were obtained from cross plots of the raw data given in Table 1), the greater the heat transfer coefficient the larger amount of entrainment, and, since, as shown, the

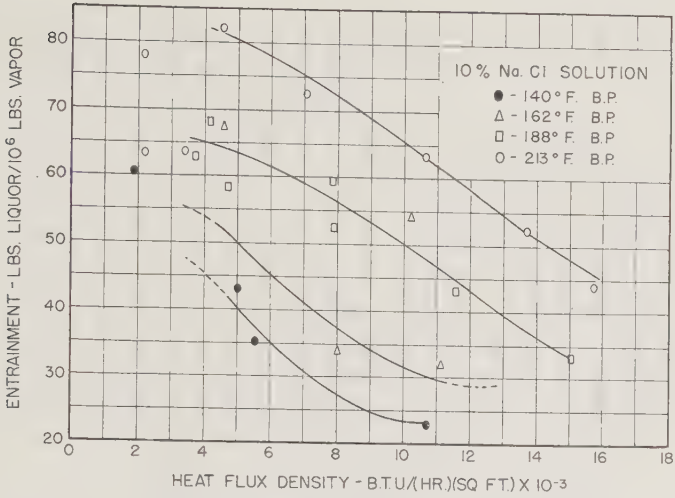


FIG. 2. Effect of Heat Flux Density on Entrainment.

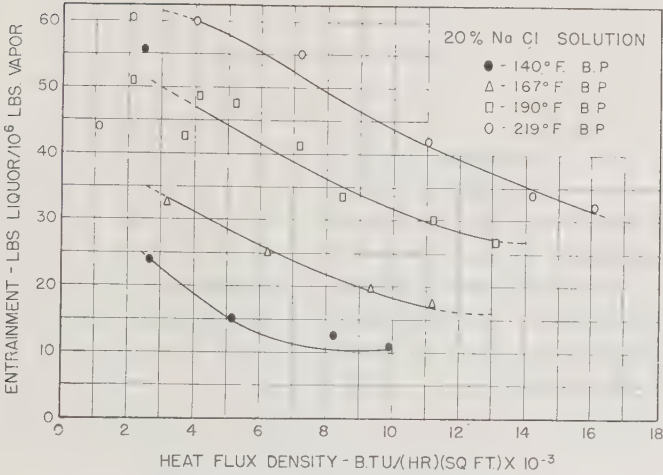


FIG. 3. Effect of Heat Flux Density on Entrainment.

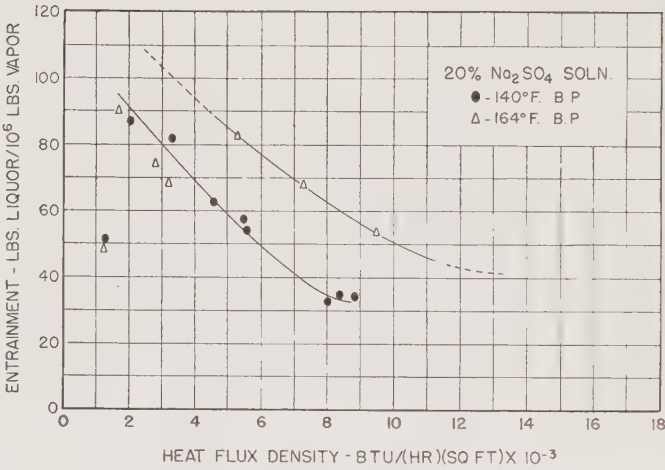


FIG. 4. Effect of Heat Flux Density on Entrainment.

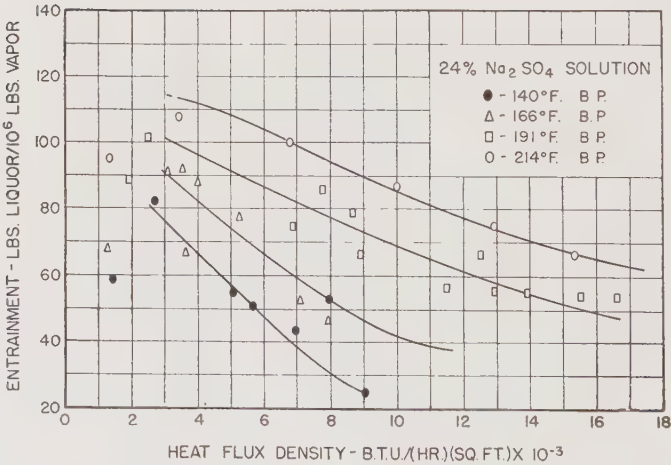


FIG. 5. Effect of Heat Flux Density on Entrainment.



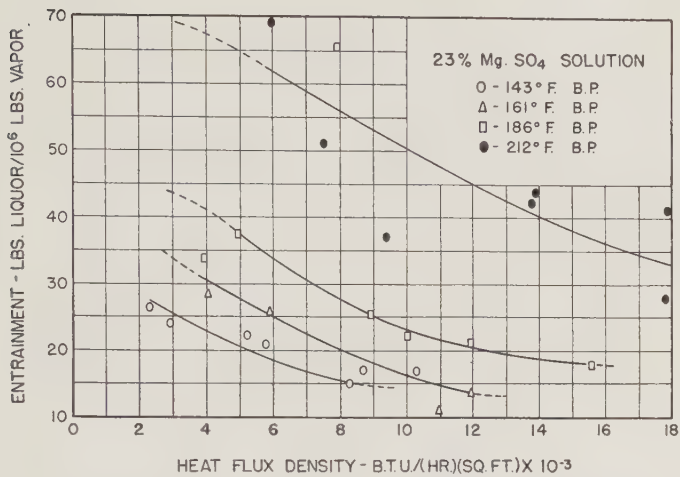


FIG. 6. Effect of Heat Flux Density on Entrainment.

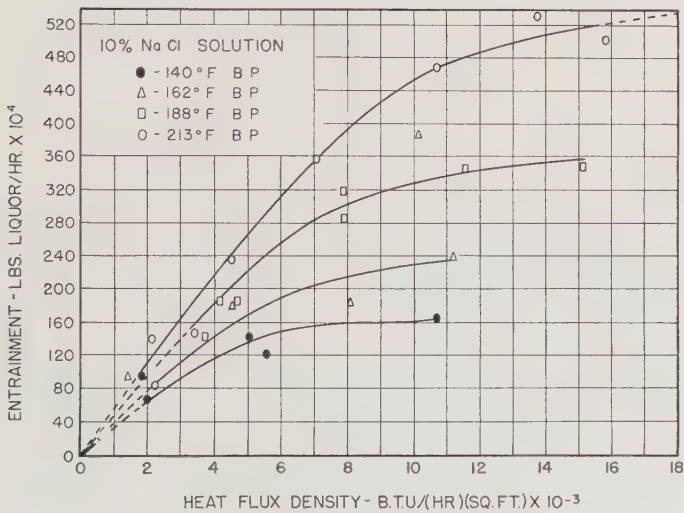


FIG. 7. Effect of Heat Flux Density on Entrainment.

greater the number of vapor bubbles formed, the greater the heat transfer coefficient, it follows that the greater the number of vapor bubbles formed the greater the entrainment. This is a logical relationship because entrainment could result when:

1. A vapor bubble pushes a droplet of liquid ahead of it as it leaves the vapor-liquid interface. The droplet of liquid could be carried overhead by the force of the rising vapor, and

2. A vapor bubble leaves the interface as a bubble of vapor with a film of liquid around it. This bubble could be carried overhead by the rising stream of vapor or could burst and throw small droplets of liquid into the vapor space.

Irrespective of whether Case 1, Case 2, or both occurs, the amount of entrainment would increase with the number of vapor bubbles.

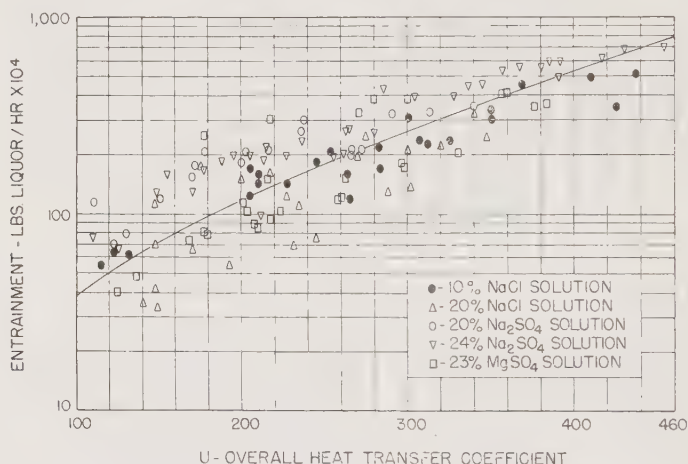


FIG. 8. Effect of Heat Transfer Coefficient on Entrainment.

In the vapor space, there is size separation of the liquid droplets as predicted by Stokes' Law. However, the effect of the size separation on the amount of entrainment is small. This is demonstrated by the fact that entrainment increases with increased boiling point. According to Stokes' Law, all other factors being equal, the entrainment should increase with decreasing boiling point because at the lower boiling points the linear velocity is higher than for the higher boiling points. This anomaly is due probably to two factors: (1) the majority of the liquid droplets in the vapor space are too small in size to have a downward force greater than the upward force of the rising vapor for any vapor velocity, and, (2) the increase in the number of liquid droplets with increased boiling point more than offshadows the greater return of liquid droplets to the liquid body at the higher boiling points.

### SPLASHING

Approximately twenty-five runs were made to study carry-over losses from splashing. The summary of the results of these runs is given in

Table 2. The experiments were conducted with the same salt solutions as used for the entrainment runs but only the 140° and 164° F. boiling points could be studied because the evaporator did not have sufficient heat transfer capacity to cause splashing at the higher boiling points.

Carry-over losses from splashing occurred in the following manner. At the low heat flux densities, vapor bubbles were released from the center of the liquid to give a fountain of boiling liquid about 6 in. high (with respect to the normal liquid level). Liquid droplets were thrown from the liquid and were carried over by the rising vapor to give carry-over losses by entrainment. As the heat flux density was increased, the height of the fountain increased, but the entrainment in pounds per million pounds of vapor decreased. This continued with increased heat flux density until the fountain of liquid reached the top of the evaporator. At this point, the carry over, in either pounds per million pounds or pounds per hour,

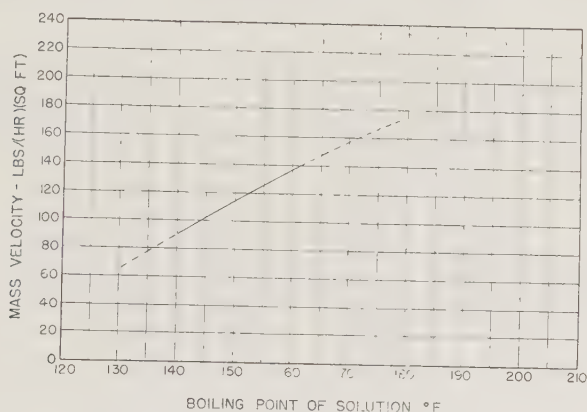


FIG. 9. Allowable Mass Velocities.

increased sharply because the liquid in the fountain splashed overhead into the condenser. These sudden increases in carry-over losses occurred at heat flux densities of 10,000 B.t.u./(hr.)(sq.ft.) for the 140° F. boiling points and of 13,000 B.t.u./(hr.)(sq.ft.) for the 164° F. boiling points. At both the 188° F. and 212° F. boiling levels, splashing did not occur even though the heat flux density was raised to more than 18,000 B.t.u./(hr.)(sq.ft.).

The allowable mass velocity to prevent splashing in the evaporator studied was about 90 lb./(hr.)(sq.ft.) for the 140° F. boiling point and about 140 lb./(hr.)(sq.ft.) for the 164° F. boiling point. For the 188° F. boiling point, a mass velocity of about 170 lb./(hr.)(sq.ft.) was reached without splashing. These results are presented graphically in Figure 9 which shows the effect of boiling point on the allowable mass velocity to prevent splashing. It should be emphasized that Figure 9 applies only to the semi-commercial horizontal-tube evaporator used in this study.

Mass velocities are not a good basis for rating vapor spaces for horizontal-tube evaporators. From this discussion, it is seen that splashing is a function of the volume of the vapor space rather than the diameter.

TABLE 2.—SUMMARY OF SPLASHING RUNS

| Run No. | Boiling Point of Solution ° F. | Sat. Steam Temp. ° F. | 10 Per Cent NaCl Solution |                                          |                                                                  |       | Mass Velocity lb./ (hr.) (sq.ft.) | Lb. Liquor Carry Over per 10 <sup>6</sup> lb. vapor | Lb. Liquor Carry Over per hour × 10 <sup>4</sup> |
|---------|--------------------------------|-----------------------|---------------------------|------------------------------------------|------------------------------------------------------------------|-------|-----------------------------------|-----------------------------------------------------|--------------------------------------------------|
|         |                                |                       | ΔT ° F.                   | Heat Flux Density B.t.u./ (hr.) (sq.ft.) | Over-all Heat Transfer Coefficient B.t.u./ (hr.) (sq.ft.) (° F.) |       |                                   |                                                     |                                                  |
| M-3     | 140.4                          | 182.3                 | 41.9                      | 13,700                                   | 327                                                              | 132.5 | 21.2                              | 21.2                                                | 199                                              |
|         | 136.2                          | 178.7                 | 42.5                      | 13,910                                   | 328                                                              | 130.0 | 35.63                             | 35.63                                               | 328                                              |
|         | 139.8                          | 179.9                 | 40.1                      | 12,500                                   | 312                                                              | 120.1 | 29.1                              | 29.1                                                | 248                                              |
| N-5     | 161.7                          | 207.7                 | 46.0                      | 19,200                                   | 416                                                              | 193.0 | 172.0                             | 172.0                                               | 2350                                             |
|         | 161.5                          | 198.4                 | 36.9                      | 13,120                                   | 356                                                              | 127.5 | 29.1                              | 29.1                                                | 262                                              |
|         | 161.5                          | 204.3                 | 42.8                      | 16,200                                   | 378                                                              | 160.8 | 34.2                              | 34.2                                                | 389                                              |
| R-3     | 140.5                          | 189.0                 | 48.5                      | 13,750                                   | 284                                                              | 135.6 | 17.91                             | 17.91                                               | 172                                              |
|         | 139.8                          | 183.8                 | 44.0                      | 12,100                                   | 275                                                              | 58.9  | 14.93                             | 14.93                                               | 164                                              |
|         | 139.8                          | 190.3                 | 50.5                      | 15,850                                   | 314                                                              | 155.5 | *                                 | *                                                   | *                                                |
| U-5     | 167.0                          | 209.0                 | 42.0                      | 14,030                                   | 334                                                              | 139.9 | 16.35                             | 16.35                                               | 161                                              |
|         | 167.0                          | 216.0                 | 49.0                      | 18,000                                   | 367                                                              | 177.2 | 23.90                             | 23.90                                               | 299                                              |
|         | 167.0                          | 213.2                 | 46.2                      | 15,970                                   | 345                                                              | 158.0 | 19.60                             | 19.60                                               | 219                                              |



TABLE 2.—(Continued)

| Run No.                                              | Boiling Point of Solution ° F. | Sat. Steam Temp. ° F. | $\Delta T$ ° F. | Heat Flux Density B.t.u./ (hr.) (sq.ft.) | Over-all Heat Transfer Coefficient B.t.u./ (hr.) (sq.ft.) (° F.) | Mass Velocity lb./ (hr.) (sq.ft.) | Lb. Liquor Carry Over per 10 <sup>3</sup> lb. vapor | Lb. Liquor Carry Over per hour $\times 10^4$ |
|------------------------------------------------------|--------------------------------|-----------------------|-----------------|------------------------------------------|------------------------------------------------------------------|-----------------------------------|-----------------------------------------------------|----------------------------------------------|
| 20 Per Cent Na <sub>2</sub> SO <sub>4</sub> Solution |                                |                       |                 |                                          |                                                                  |                                   |                                                     |                                              |
| AA-10                                                | 140.1                          | 183.2                 | 43.1            | 14,420                                   | 335                                                              | 141.5                             | *                                                   | *                                            |
| 11                                                   | 140.1                          | 183.2                 | 43.1            | 12,900                                   | 299                                                              | 125.0                             | 68.0                                                | 603                                          |
| 12                                                   | 140.1                          | 174.1                 | 34.0            | 11,390                                   | 334                                                              | 110.8                             | 44.1                                                | 345                                          |
| AB-8                                                 | 164.0                          | 198.2                 | 34.2            | 11,980                                   | 350                                                              | 122.2                             | 64.3                                                | 556                                          |
| 9                                                    | 165.3                          | 212.0                 | 46.7            | 18,900                                   | 404                                                              | 189.5                             | 102.2                                               | 1370                                         |
| 10                                                   | 165.3                          | 206.6                 | 41.3            | 15,610                                   | 378                                                              | 154.1                             | 50.0                                                | 545                                          |
| 24 Per Cent Na <sub>2</sub> SO <sub>4</sub> Solution |                                |                       |                 |                                          |                                                                  |                                   |                                                     |                                              |
| BA-8                                                 | 140.0                          | 179.8                 | 39.8            | 11,490                                   | 288                                                              | 111.25                            | 31.5                                                | 247                                          |
| BB-7                                                 | 166.4                          | 201.3                 | 34.9            | 13,980                                   | 400                                                              | 130.5                             | 42.5                                                | 392                                          |
| CC-3                                                 | 166.0                          | 200.0                 | 34.0            | 13,220                                   | 389                                                              | 129.0                             | 40.4                                                | 368                                          |
| 23 Per Cent MgSO <sub>4</sub> Solution               |                                |                       |                 |                                          |                                                                  |                                   |                                                     |                                              |
| FF-4                                                 | 144.0                          | 193.2                 | 49.2            | 13,800                                   | 280                                                              | 140.0                             | 9.56                                                | 94                                           |
| 5                                                    | 142.0                          | 188.3                 | 46.3            | 13,800                                   | 298                                                              | 139.0                             | 19.80                                               | 194                                          |
| GG-4                                                 | 161.8                          | 211.1                 | 49.3            | 15,120                                   | 307                                                              | 150.1                             | 10.22                                               | 108                                          |
| 6                                                    | 164.3                          | 214.1                 | 49.8            | 17,800                                   | 357                                                              | 174.5                             | 22.90                                               | 282                                          |

\* Could not be measured.

Even with a large diameter evaporator, splashing would occur if the fountain of liquid reached the top of the evaporator. A more logical relationship would be to rate vapor spaces on the basis of the volume velocity. The results of this study showed that splashing did not occur if there was available one cubic foot of vapor space for every cubic foot of vapor evaporated per second. This relationship should be used only as a guide since it is based on results for one evaporator and for only two points on this evaporator. However, this relationship has been used with good success in the design of evaporators for organic compounds (for example, a heat exchanger cooled with propane). The volume produced by this relationship should be distributed to give a height to diameter ratio of 1.5 to 1.0.

### FOAMING

The original problem did not concern carry-over losses from foaming but considerable difficulty was experienced at first in preventing foaming.

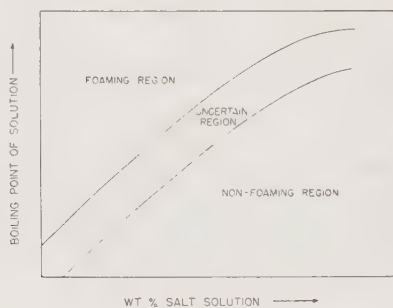


FIG. 10. Effect of Solution Concentration and Boiling Point on Foaming.

The results of these studies are of sufficient interest for reporting and are summarized.

1. All sodium chloride solutions with concentrations below 10 per cent and near the crystallization point foamed. No foaming occurred in the 10 to 25 per cent sodium chloride concentration range. The sodium sulfate solution foamed up to 20 per cent concentration while the magnesium sulfate solution foamed up to 10 per cent concentration.

2. Foaming occurred more readily at the higher boiling points. For example, a 20 per cent sodium sulfate solution foamed at the 188° and 212° F. boiling points but did not foam at the lower boiling points. However, when the concentration of the sodium sulfate solution was raised to 24 per cent, no foaming occurred at any of the boiling points.

3. Foaming did not occur with either distilled or city water under any temperature conditions. However, when 0.01 per cent duponal was added to the water (with a resultant lowering of the surface tension to 55-60 dynes per cm.) foaming occurred.

This effect of concentration and boiling point of the solution on foaming is shown in a general way in Figure 10. Here, it is shown that for constant concentration of salt solution, the foaming tendencies increase

with boiling point of solution. Also, for constant boiling point, the foaming tendencies increase the more dilute the solution.

A relationship existed between entrainment and foaming. The sodium sulfate solution foamed easier than the other solutions and also had the highest entrainment losses. This is expected because, as explained, entrainment was the greatest, the smaller and the greater the number of vapor bubbles. With a large number of small vapor bubbles, there is a tendency to form a stable foam.

### DISCUSSION OF RESULTS

Carry-over losses in a horizontal-tube evaporator can be caused by entrainment, splashing and foaming. Of these, splashing and foaming are the most serious because they result in large carry-over losses while entrainment losses usually are small. Very likely, most cases of gross "entrainment" losses which have been reported are caused by either splashing or foaming.

Entrainment results when liquid droplets, which are thrown into the vapor space by vapor bubbles, are carried overhead by the rising stream of vapor. Entrainment, in pounds of liquor per million pounds of vapor, decreases with increase in heat flux density at constant boiling point up to a certain heat flux density. However, continued increase in the heat flux density will cause the solution to boil so violently that liquid is splashed overhead. This will result in excessive carry-over losses. Therefore, in a given evaporator, there is an optimum heat flux density to give a minimum carry over. This optimum occurred in the evaporator studied if the heat flux density was sufficient to give one cubic foot of vapor per second for every cubic foot of vapor space.

Carry over by entrainment increased with increased boiling point. However, at the higher boiling levels, the heat flux densities to cause splashing were considerably higher than at the lower boiling points.

The factors affecting foaming still retained their elusive character and this study shed very little light in this direction. There was some indication that the smaller the size and the greater the number of vapor bubbles formed, the more the chance of foaming. Also, it was shown that certain concentrations of salt solutions did not foam while others did.

In design of a horizontal-tube evaporator, attention should be given to splashing. This study indicated that splashing can be eliminated by providing one cubic foot of vapor space for every cubic foot per second of vapor. This relationship should be used only as a guide, however, because it was based on two points in one evaporator. However, it has been used with success in the design of evaporators for organic compounds. Designing for splashing losses will insure that entrainment losses will be small.

As far as foaming is concerned, if there is evidence that a solution has foaming tendencies, a horizontal-tube evaporator should not be used. However, if it is necessary to use a horizontal-tube evaporator, an anti-foam agent should be added to the solution and provision should be made in the design for the installation of a steam coil foam breaker in the vapor space.

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